

# Self-Sustaining Robotic Ecologies and Space Architecture

**Presentation to the AIAA Design Engineering Technical Committee**

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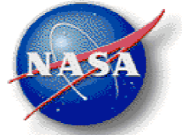
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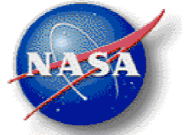
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Reno, Nevada, January 6th 20004



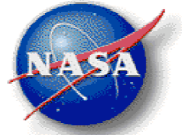
# Outline

- From “one shot” explorations to infrastructure building
- Challenges to infrastructure building
- Modularity and self-sustaining robotic ecologies
- A pathway to human presence
- Robotic “architecture”
- The “Robosphere” concept
- Conclusions



# Goals of robotic exploration

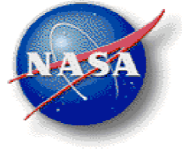
- Human presence on planetary surfaces or in deep space colonies will need to be preceded by robotic explorers and builders.
- **Generally accepted goal:** Acquire a complete understanding of the environment to be explored.
- **Not yet seriously considered:** A safe habitation complex for the first human explorers, including the means for in situ resource utilization.



# The approach

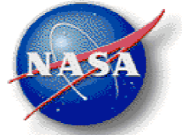
- Extend robotic “life”
- Build infrastructure
- Organize robotic “ecologies” for sustained exploration and infrastructure maintenance
- Piggyback on stable robotic infrastructures to prepare for a sustain human presence





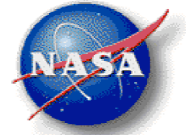
## From “one shot” to infrastructure

- Robotic exploration of Mars has been a "one shot" approach
- Even solely for scientific exploration it would clearly be desirable to have robots on Mars that can last for much longer periods of time.
- I propose that there is an approach to sustained robotic exploration that can also pave the way to future human presence.
- The idea is to continue building a robotic infrastructure with every mission we send.



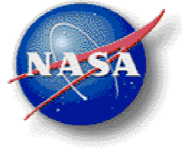
# Bootstrapping a robotic ecology

- A simple starting point for this infrastructure might consist of relatively simple modular robots. Imagine for instance 2 "spider-like" robots built out of small modular snap-in pieces, a bin of these pieces and a bin of snap-in end effectors.
- One of the spiders breaks down, i.e. one of its modules needs to be replaced. The second spider comes to the rescue and helps the first one replace the broken module.
- Assuming the input of fresh modules, this process can continue indefinitely (we could “seed” parts and modules the robots could access for self-repair)
- We could seed areas of interest with sturdy power stations (solar, chemical..) that teams of robots could use to recharge themselves.



# Bootstrapping (cont.)

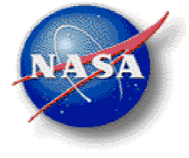
- Now start separating robotic explorers from robotic "mechanics",
- start adding a category of mechanics that are able to fix at least some of the broken modules (and which in turn can be fixed by the original mechanics),
- The need for a fresh influx of modules is thus reduced.
- I submit that we could bootstrap a robotic ecology until it needs very little material from earth and can rely mostly on in-situ resources.
- We refer to such self-sustaining robotic ecologies as "robosphere".
- We use the word ecology to emphasize the fact that we are not dealing only with robotic cooperation and exchange of information, but also with exchange of energy and materials.



# Spacecraft longevity

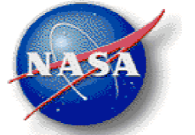
**The longevity of exploration craft on the Mars surface has been varied and mainly limited by the availability of energy.**

- The Pathfinder lander, which was solar powered, lasted 83 sols (Martian days, about 85 Earth days ).
- Its experimental microrover, Sojourner, was still working (daytime only; battery was dead) at the time the lander died. Primary mission plan was 30 days for the lander and 7 days for the microrover experiment. Extended mission was one year for the lander and 30 days for the rover.
- The Mars Polar lander, which was lost on arrival was designed to have a nominal mission of a month or two. The Mars Exploration Rovers (presently on their way to Mars) are designed to have a primary mission of 90 sols.



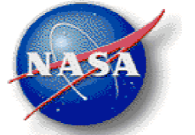
## Spacecraft longevity (cont.)

- The Viking Landers, (nuclear powered) lasted for four to six Earth years. The Viking 1 Lander operated from 20 July 1976 until 13 November 1982 when a faulty command sent by ground control resulted in loss of contact. The Viking 2 Lander operated on the surface for 1281 sols and was turned off on April 11, 1980 when its batteries failed.
- The upcoming ESA lander, Beagle 2, is designed to have a primary mission of 180 sols and an extended mission of 669 sols (one Mars year). It doesn't have a rover, but it has a "mole".
- The use of nuclear power can make a huge difference, but the risks of nuclear use and, to an even greater extent, the perception of risk constitute a problem space exploration must contend with.
- Clearly the ultimate solution is to produce power from in-situ resources, and this would be the strategy required by the Robosphere approach proposed in this paper.



## The challenges to both sustained exploration and infrastructure building

- The basic challenges: mechanical and energetic.
- Enough energy can be made available by solar, nuclear power (as has already been demonstrated) or other in situ resources,
- Mechanical breakdowns remain both a practical and a conceptual challenge
- Obsolescence must be dealt with as well

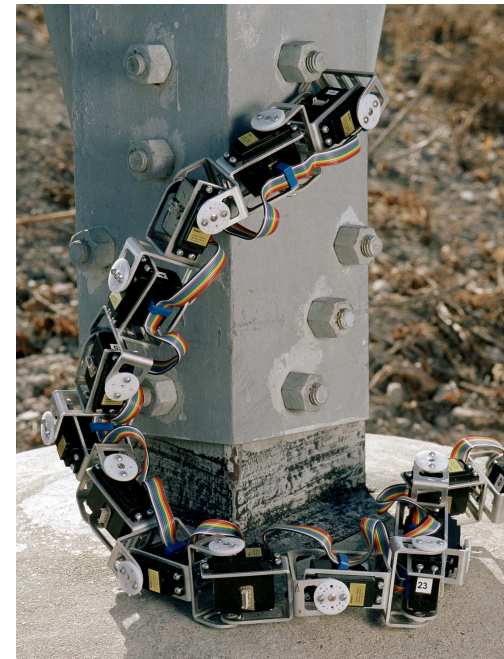
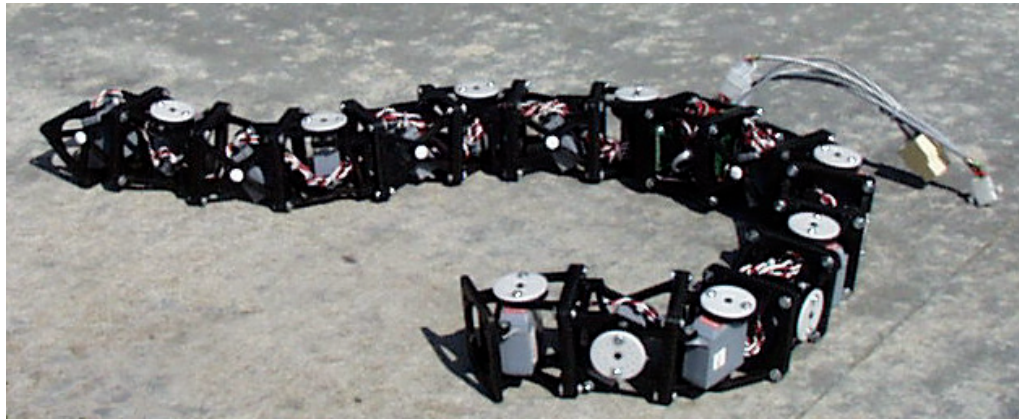


# Meeting mechanical challenges

- Small robotic teams capable of mutual repair are a possible answer
- Biological systems provide the conceptual proof for the possibility of limited self-repair as well as potential models for robotic implementations.
- Present robotic research in the direction of self-repair is based on modular and self-reconfigurable systems,
- Modular robotic systems with the ability to autonomously swap faulty (or obsolete) modules for new ones have not yet been developed
- This logical first step is not too far into the future.

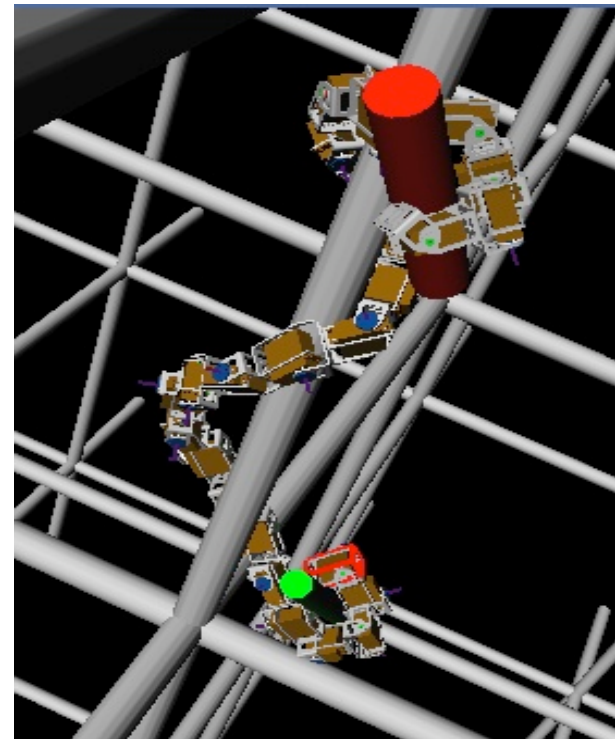
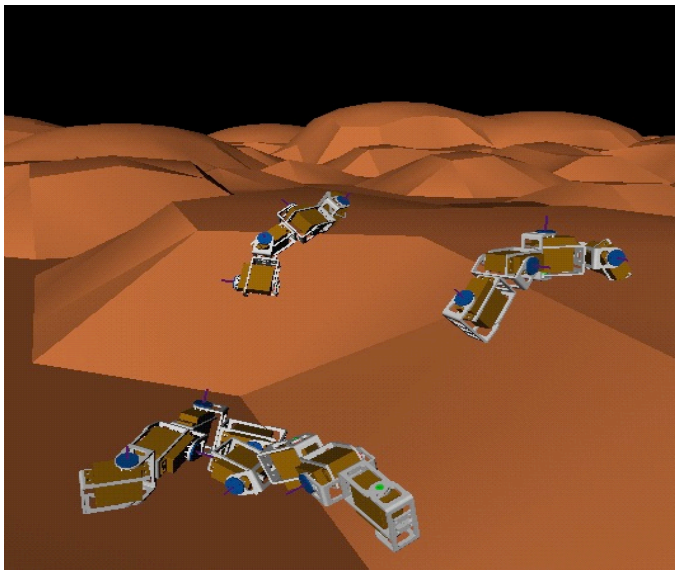
# NASA Ames “snakebots”

(some based on Mark Yim’s “polybot”)



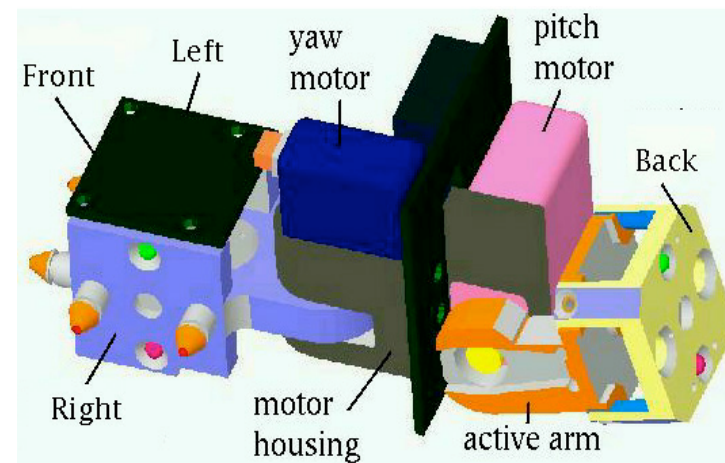
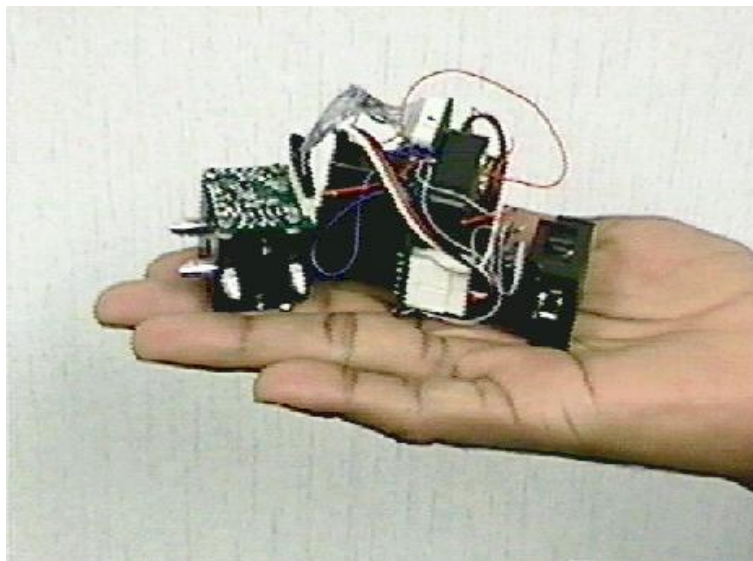


# Snakebot application concepts

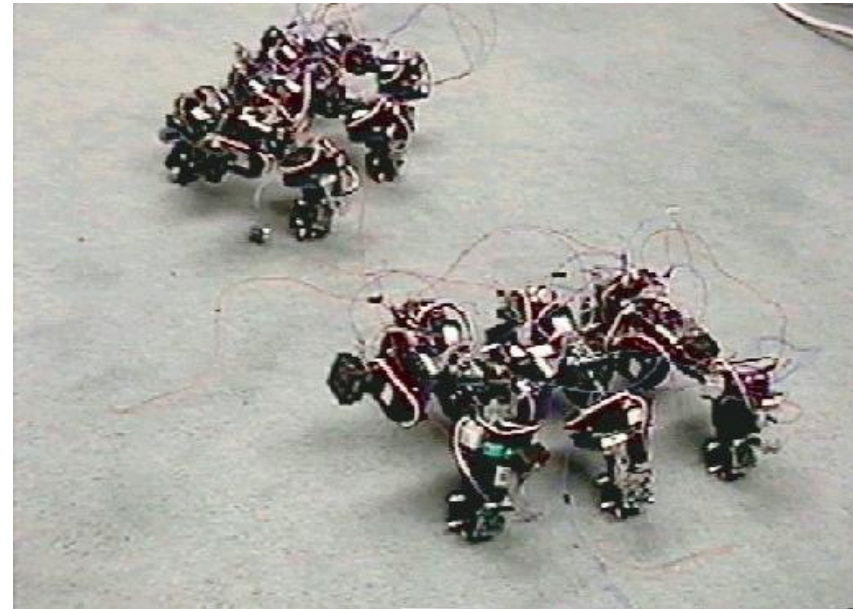
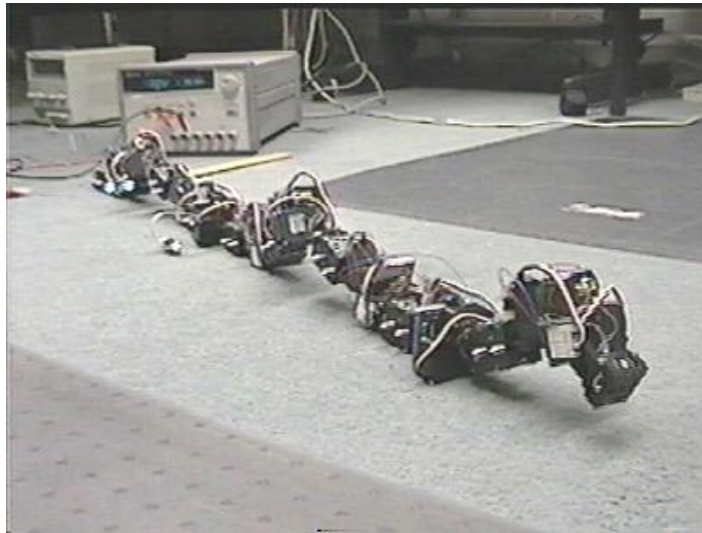


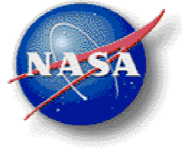
# CONRO Modules

(Shen and Will, ISI, USC)



# CONRO modules configurations





# Robotic outposts

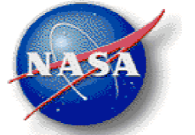
Given the fundamental challenges of energy availability and autonomous mechanical repair, robotic outposts will need to be the fundamental unit for sustained planetary robotic exploration.

- means for energy production and delivery to robotic units,
- functional specialization of robotic units.
- Shelters to facilitate various robotic functions and to reduce mechanical degradation.
- Robotic units specialized for shelter construction and repair
- Coordinated local and Earth guided control
- Increasing level of autonomy and functional specialization



# The arrival of human explorers

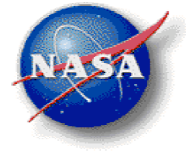
- Functionalities developed for robotic survival will be readily transferable to the needs of human explorers.
- The major transferable functions will be energy production and shelter construction.
- Sheltering and infrastructure suitable to humans would require major reprogramming of the constructor units, but the basic capabilities would be in place and would be well tested.
- Building a self-sustaining robotic infrastructure would certainly be more costly at the start but it would start a long term commitment to planetary exploration with small risk of major failures.



## The arrival of human explorers (cont.)

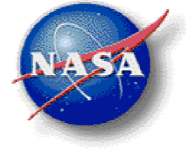
- Ultimately, as stated above, human presence could be accommodated as a natural evolution of the robotic infrastructure
- While oxygen and food production tasks could be included as a long term mission and be ready for the arrival of the crew.
- A test for such a task had already been included in the ill-fated Mars Polar Lander mission.
- The flight demonstration, called Mars ISSP Precursor (MIP), where ISSP stood for "In-Situ Propellant Production", comprised five distinct experiments to test environmental constraints on solar energy production and to generate pure oxygen from the Martian CO<sub>2</sub> atmosphere<sup>3</sup>.





# ROBOTIC ARCHITECTURE

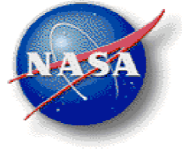
- The adjective "robotic" could signify both architecture that uses robots for construction
- a role for architecture in machine "societies"?
- Does the fact that machines will eventually acquire high levels of perception and "consciousness" imply that architectural thinking will become part of the environments that will support these machines?
- Architectural thinking follows a continuum from practical space elements to facilitate activities, to satisfying esthetic needs.
- **The boundary is not always clear for humans and it may eventually become increasingly fuzzy for machines as well.**



# Architecture Evolution

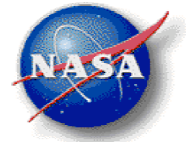
- Sheltering for robots should be able to be adapted to human presence, so that the architecture should be able to evolve from machine use to human needs.
- How will the increasing symbiosis of humans with (intelligent) machines, especially in space and planetary environments, affect architectural thinking and practice?
  - machines as constructors.
  - machines as an architectural medium. (Earth examples: ship, planes etc.)
  - machines as possible "consumers" of architecture





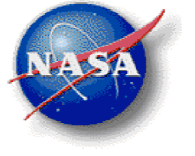
# Architecture Emergence

- Architecture becomes a natural part of the integration process of robotic and human systems and
- Must arise as part of the process (e.g. natural architecture of living systems)
- It becomes increasingly difficult to produce a design to be instantiated independently of the system to be sheltered
- The architect may need instead to intervene in the process to cause the appropriate architecture to emerge.



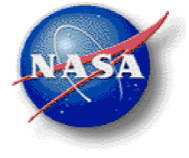
# Robosphere

- Just like terrestrial architecture needs to find harmony with surrounding nature, space and planetary architecture will need to co-evolve with the robotic machine environment that human life will strongly depend on.
- The robosphere concept is inspired by Biosphere 2, the experiment intended to test the stability of artificial ecosystems.
- A robosphere facility could be built to test the following:
  - stability of a self-sustaining robotic ecology.
  - how an environment that can sustain human life can be co-evolved with the necessary robotic functionality.
- Held a robosphere workshop in 2002 (at NASA-Ames). Planning for the next one in 2004.



## TOWARDS ROBOSPHERE: TECHNOLOGY PROGRESS.

- Robots will always be **first**.
- If we develop the technology for efficient, stable, long term robotic exploration, then human access to new space frontiers will be facilitated as well.
- Most robotic research deals with increasing autonomy, path planning, vision, but what is needed is to make robotic repair and survival the most important robotic task.
- Modular and self-reconfigurable robotics.
- Automated construction of human (and robotic) habitats.
- Self-reproduction.
- Multiple-scale robotics.



# CONCLUSIONS

- We propose that it would be feasible and desirable to approach robotic exploration of planetary surfaces as an infrastructure building program
- We rely on the concept of self-sustaining robotic ecologies (robosphere).
- Current ideas in modular and reconfigurable robotics, as well as work on robot based construction, show that progress in this area can be made relatively short term.
- We argue that typical architectural concepts need to be expanded to allow for increasingly blurry distinctions between what are "human centered" and "machine centered" environments.
- More esoteric notions of robotic self-reproduction and multi-scale (down to the nano level) robotics need to be considered for future study